NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 1041

THE EFFECT OF SET SIZE ON COLOR MATCHING

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Naval Medical Research and Development Command
Research Work Unit M0100.001-1022

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SUMMARY PAGE

PROBLEM

To determine the effect of increasing the number of colors used in a color coded display on the time required to match the colors.

FINDINGS

Response time (RT) does not increase disproportionately as the number of colors increases. As the number of colors in the set increases above five or six, the increment in RT is reduced by half, but the mean number of errors in color matching increases sharply.

APPLICATION

In introducing color coding to CRT displays, as many as six carefully selected colors can be used without unduly increasing either the operator's response time or error rate. It is possible that with the appropriate set of colors, an even larger number can be used.

ADMINISTRATIVE INFORMATION

This research was conducted as part of the Naval Medical Research and Development Command Work Unit M0100.001-1022 - "Enhanced performance with visual sonar displays." It was submitted for review on 28 Dec 1984, approved for publication on 14 Jan 1985, and designated as NSMRL Report No. 1041.

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ABSTRACT

The time required to match a colored stimulus to one of a set of colors was measured as a function of color sets ranging in size from 2 to 10. Reaction time (RT) increased linearly with increases in set-size to five or six, after which the increase, although still linear, was less steep. Mean errors increased sharply with set sizes of 9 and 10. The relative RTs to the different colors remained constant despite changes in the experimental method.

color-coded CRT

INTRODUCTION

Current monochromatic sonar displays are soon to be replaced with chromatic ones. It is anticipated that color coding will enhance the performance of the sonar operators. A number of review articles, however, have pointed out that there are both advantages and disadvantages to the use of color coding, (1-6). That is, compared to other methods of coding--shape, symbols, alphanumerics, for example--color does not always improve performance. Used inappropriately, it may even degrade performance. The correct application of color coding depends on the nature of the task to be performed, the choice of colors, the number of colors, ~~and so~~ on. etc. Moreover, as Laycock has pointed out, it is often the case that when general recommendations are made regarding color coding, it is not specified whether the recommendations should be applied to signal lights, instrument dials, or to displays (7).

Although a great deal of research has been done on many of these problems, relatively few experiments have been carried out using the cathode ray tubes (CRTs) on which actual displays are produced and which operators actually monitor. Since most of the available data on color coding was obtained with reflected or projected color stimuli, it is not certain to what extent they can be generalized to CRT displays. Studies using actual CRTs are necessary (7,8).

There is general agreement that color improves performance when searching for a target in a complex display. Still, even in this application, a number of questions remain to be answered. For example, how many colors can profitably be used? Which colors are the best colors? The answer to the first question devolves to two other problems, how many colors can be discriminated, and what is the effect on performance of an increase in the size of the set of colors to be discriminated?

Although the estimate of the number of colors which the normal individual is said to be able to discriminate is truly astronomical (9), this surely holds true only under ideal conditions and using the most sensitive testing methods. Under ordinary practical conditions, the number of colors which can be used for color coding is extremely limited; the number is almost invariably estimated to range from four to 10 (2,4,7,9-16). Meister and Sullivan (17) listed the 10 most widely recommended colors, but typically the emphasis is on the lower numbers. Conover (11,12) for example, recommended no more than eight colors under "ideal" conditions and no more than five under degraded viewing conditions; Brooks (13), Krebs et al. (4), and Cook (2) recommended no more than five.

As the number of colors with which the observer must deal increases, various aspects of performance are degraded. When they tested accuracy of identifications, Halsey and Chapanis (9) found that 98% accuracy could be achieved with 10 colors, but this declined steadily to only 72% accuracy with a set of 17 colors. Other studies have measured the time required to identify or respond to the colors; as the size of the set of colors increases, reaction time at some point tends to increase. Brooks has reported (13), however, that there is no increase in RT until the set size is greater than five.

There is also tolerable agreement on which colors should be used, within rough limits. There is quite close agreement in much of the literature about the choices of red, orange, and yellow. The color specifications published by Laycock (7) are a good example of a set of recommendations. Figure 1 shows his recommendations for a set of six colors. Laycock's specification for "green" is more restrictive and more to the yellow-green than is usually the case; his blue is somewhat different from other choices, and many recommendations do not include a magenta as he does.

In short, despite rough agreement, there is a certain amount of variability in the recommendations of different investigators, and it is not clear how these differences in opinion can easily be resolved. Often the experimental method used to choose a set of colors is lengthy, time-consuming, and cumbersome. An example is the series of paired comparisons carried out by Butler and McKemie (18) to ascertain which of a set of 46 colors were the brightest and the most conspicuous. The amount of work needed to make the series of paired comparisons for 46 colors is enormous, of course, and Butler and McKemie went through the procedure twice, for brightness and for conspicuity. They did this because they could not be sure which characteristic was more important. Since the rankings they obtained for the various colors were different for brightness and conspicuity, it still remained to decide which should be the determining factor in choosing a set of colors for coding purposes.

Such a decision must, of course, be based on how well the operators using the color-coded displays can perform their assigned tasks. One suggested application of color coding to sonar displays is to assign different colors to the various target-tracks; in situations in which large numbers of targets are being tracked, this should help the operator to categorize them. Moreover, if alphanumeric data about each target, displayed in a separate section of the screen, are also printed in the same color as the target-track, the operator should be able to refer to the appropriate alphanumeric data for each track more quickly.

The questions immediately arise, how many colors can be discriminated in such a display, and what is the degradation in reaction time as the operator tries to match the colored target-track with the appropriate color in another part of the display? In this study, the time required to match sets of easily distinguishable colors displayed on a CRT was measured as a function of the number of colors with which the observer was required to deal.

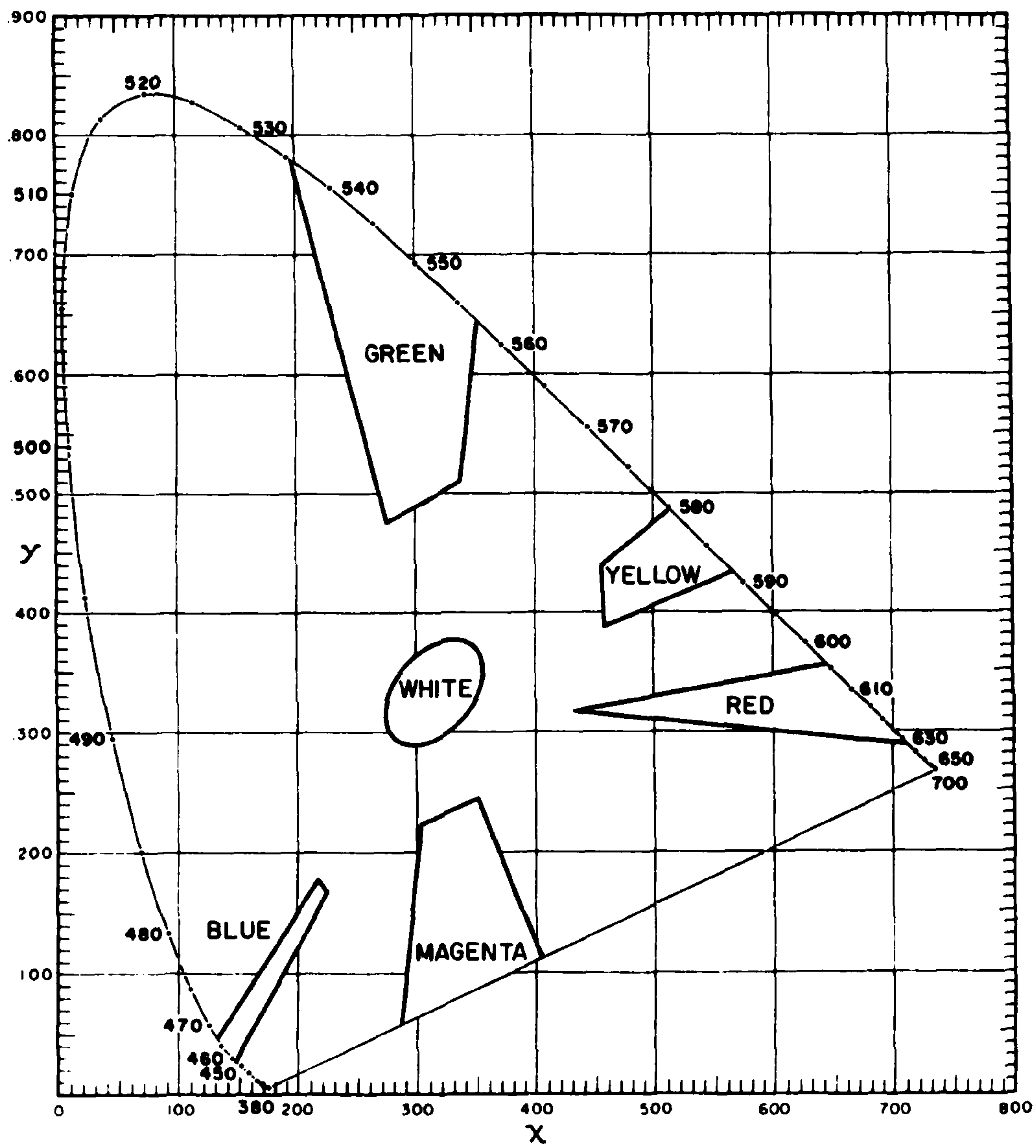

Fig. 1. A typical set of CIE specifications for six colors to be used for color-coding (taken from Laycock (7)).

EXPERIMENT I

METHOD

Subjects. Six color normal staff members of the laboratory served as subjects. All but one had experience with this type of color matching experiment.

Apparatus. The stimuli were presented on an Advanced Electronics Design, Inc. Color Graphics and Imaging Terminal, Model 512. A series of circular stimuli were arranged in the pattern of a telephone pushbutton keypad: a 3 x 3 matrix plus one more stimulus centered below these. Each stimulus was a circle 1.2 cm in diameter, separated by .5 cm from the adjacent stimulus. The total arrangement thus measured 4.6 cm wide by 6.3 cm high. A vertical line 6.5 cm long and 0.5 cm wide could appear below the center of this display with the top of the line 4 cm below the lowest circle. At the viewing distance of about 60 cm, the circular stimuli subtended 1.15 deg vis angle, and the vertical line subtended 6.15 deg vis angle in length and about .5 deg vis angle in width.

The subjects viewed the display in a dimly lighted room. The mean luminance of the stimuli ranged from about 5 to 50 foot-lamberts (ft-L) against a background of about .02 ft-L.

The circles could be filled with either a white light or various colors. No attempt was made to equate the brightness of the colors. Rather, differences in brightness were used to help differentiate them; thus, for example, both a light and a dark blue were included in the set. The ten colors were judged by four color-normals to be distinctly different.

A set of ten colors was used in the experiment. The C.I.E. coordinates of these colors are listed in Table I and were determined according to the following procedure. A single stimulus was displayed on the CRT, in the same size used in the experiment, and two color normal observers made a visual match to a Munsell chip. The Munsell Book of Color was positioned adjacent to the screen and the level of illumination (provided by an Illuminant C source) was adjusted to be similar to the luminance of the stimulus. Measurements were then made of the Munsell chip with a Spectra-Pritchard Model 1980 photometer using the photopic, red, and blue filters. The tristimulus values of the Munsell chip were then obtained from the values provided by the Nickerson tables (19-21). This enabled correction constants to be calculated for use in measuring samples similar in chromaticity to the chip. Measurements were then made of the stimulus, and the correction factors were applied, yielding the chromaticity coordinates for the stimulus. The formulas used were taken from the photometer instruction manual. This procedure was repeated for all of the stimuli.

Procedure. The ten circles were always visible to the subject. During a given segment of the experiment, from two to all ten of the circles were filled with colors which were also always visible. Table I gives the combinations of colors used, and Fig. 2 shows them plotted on the CIE diagram. For the set of two, the colors were yellow and dark blue; for the set of three, red was added; for the set of four, blue-green (aqua) was added to the preceding three, and so on.

Table I. The colors listed in order of their inclusion in the sets of two to ten colors

Set Size	Color	C.I.E. x	C.I.E. y
-	Yellow	.43	.45
2	Dark Blue	.15	.06
3	Red	.60	.34
4	Aqua	.24	.38
5	Purple	.27	.13
6	White	.28	.30
7	Orange	.57	.36
8	Green	.29	.54
9	Pink	.37	.34
10	Light Blue	.17	.11

The set sizes were presented in random order, and the colors were positioned in a different random order for each set size. The circles were always filled, however, starting at the upper left ("1") and proceeding to the right and then down (see Fig. 9). Before beginning a test, the subject was permitted to study the set of colors as long as he wished in order to learn their arrangement.

During the experiment, the vertical line appeared (one second after a warning tone) matched in color to one of the colors in the set. The subject's task was to match the line to the correct color in the set as quickly as possible by pressing the button on a telephone keypad which corresponded to the position of the matching color. The keypad corresponded exactly to the stimulus arrangement. Each color in the set was presented in random order until the subject had made 20 correct responses to the set size of two, 30 correct responses to the set size of three, and so on. With a set size of 10, the subject responded until he had made 100 correct responses to the 10 colors presented randomly with an equal probability of occurrence of each color in each set. The computer tabulated the incorrect responses, but they were not included in the calculation of the mean reaction time.

To obtain a comparison set of reaction times not involving color matches but only the time needed to respond to the correct position of the button, the subjects were tested with the same stimulus

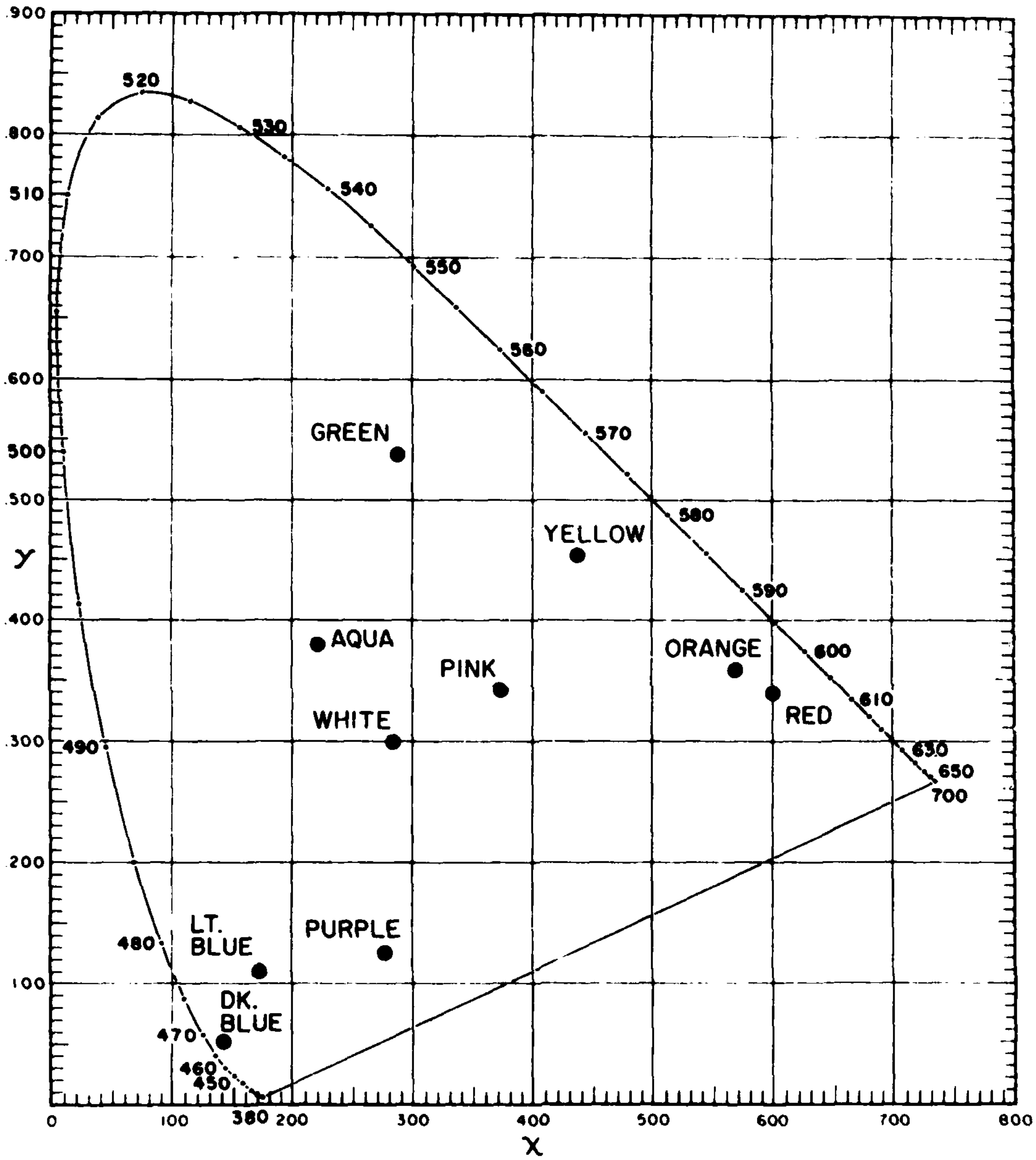

Fig. 2. The CIE coordinates of the 10 colors used in these experiments.

configuration. The vertical line, however, was not presented. Instead, one of the circles was turned to white, and the subject was required to turn it off as quickly as possible by pressing the appropriate button. Once again, the number of circles in the set to be responded to ranged from 2 to 10, and each position was responded to 10 times. The subjects were presented with the set sizes in the same random order as they received with the colored sets. Half the subjects were tested with the chromatic stimuli first, and half were tested with the achromatic stimuli first.

RESULTS

Effect of Set Size on Reaction Time. To assess the time required to respond to different set sizes, it is necessary to take into account the time required simply to push the response buttons. As set size increases, response time will increase because there are more buttons to manipulate and not simply because of the increase in the number of colors. The mean RTs to the various achromatic sets must therefore be subtracted from the color sets of the same size. Figure 3 shows these adjusted mean RTs for the correct color matches for the various sets of colors. As set size increased, the time taken to match the stimulus line to the array of colors also increased. When the subjects had to choose between only two colors, the mean RT was about 80 msec; as the set size increased from two to five colors, mean RT increased by about 80 msec with each additional color in the set. With further increases in set size, however, mean RT increased by only about 40 msec for each additional color. Unexpectedly, the RT increments did not become excessively large with the largest set sizes. It should be noted that this was also true for the original RTs before the achromatic RTs were subtracted.

Color Mismatches. Table II gives the colors which were incorrectly matched to the test stimulus. It is clear that some of the errors were simply incorrect button-presses rather than color confusions, since some of the errors involved buttons which were adjacent to the correct button. Moreover, four of the incorrect responses involved buttons for which no color was displayed; these were, of course, clearly nothing more than incorrect button presses. Of interest, then, are the consistent patterns. Pink, for example, was consistently confused with white by one subject and with yellow by another subject. Orange was repeatedly confused with yellow by one subject, and aqua was confused with green. Red was confused with purple and orange. The other colors produced either few errors or random errors. Orange produced a very long RT, and pink a moderately long RT, but red was responded to very quickly. There is, thus, little correlation between RT and error rate.

Reaction Times to the Individual Colors. To assess the differences in time taken to respond to the various colors, it is again necessary to take into account the time taken to respond to the different buttons. Now, however, we are concerned not with mean RTs to the entire set, but with RT to each button. Figure 4 shows the mean

Table II. Mismatches to the stimulus colors in Expt. I

	Stimulus Colors									
Subj.	D. Blue	Yellow	Red	Aqua	Purple	White	Orange	Green	Pink	L.Blue
RR	L.Blue	Aqua(2) *	* Purple(2) Orange(2)	White(2) D. Blue	Aqua	Green	Yellow(7)	Orange	White(6)	
AJ	Red Aqua	Red White	Purple Yellow	D. Blue Purple	D. Blue(2) Yellow	Aqua Pink(2)	Yellow Red			
CS	Orange Red		Yellow D.Blue Purple Orange Aqua	Green(7) L.Blue Purple			Yellow	Pink	Yellow(4) White(3)	
JD	Aqua	Aqua White	White			Yellow				D.Blue
JS	Green	Aqua	Orange Aqua			L.Blue			White	
DK		Orange	* * Aqua	Yellow Orange	Yellow		Red			D.Blue
Total Errors	7	9	18	16	5	6	11	2	14	2

* No color presented in location to which subject responded.

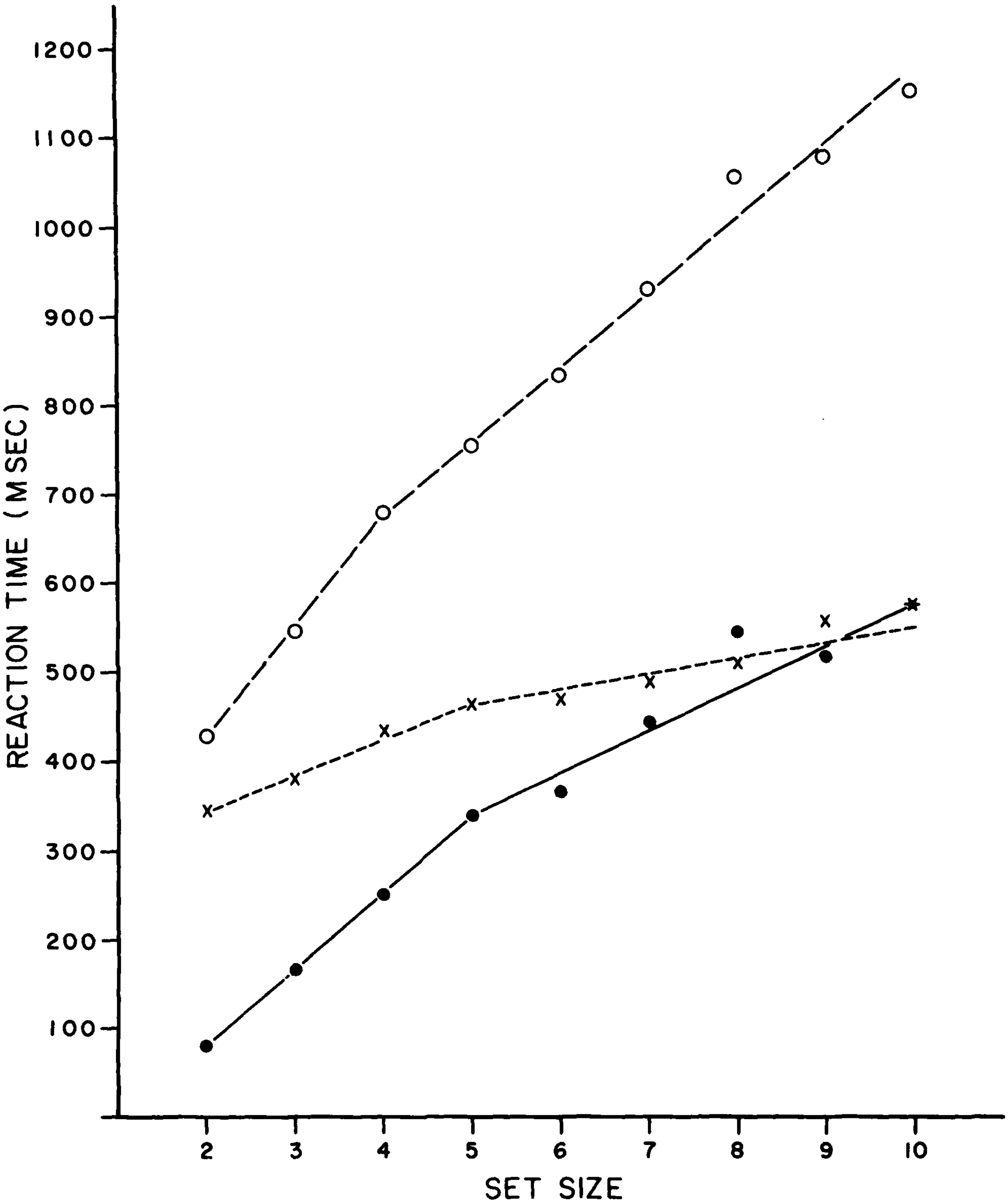

Fig. 3. Mean reaction-times for the various sets of stimuli in Experiment I. The open circles show the RTs of the matches to the chromatic stimuli; the Xs show the RTs to the achromatic stimuli; the filled circles show the differences between these two.

response times to the 10 buttons from the procedure which did not involve color matching. It is clear that RT was fastest to buttons 4, 5, and 6 in the middle of the keypad. There is no doubt that the subjects adopted the most reasonable strategy of resting their fingers on these buttons, so that they would be able to move either up or down most efficiently. It is also clear that it was easier to move up than to move down; RTs to buttons 1, 2, and 3 were higher than to the center buttons, but not as high as RTs to buttons 7, 8, and 9. The longest RT was to button 10, the lowest on the keypad. These differences are highly significant ($F(9,5) = 4.13$, $p < .01$). Indeed, the differences in RT to the various buttons were significant for each of the six subjects. For each subject, therefore, the RT to a given button must be subtracted from the RT to the color corresponding to that button.

Figure 5 shows the mean RTs to the various colors from which the RTs to the buttons for these colors have been subtracted, listed in order of increasing RT. Even after subtracting the times required to push the buttons, the RTs to the colors, which range from 386 ms for dark blue to 926 ms for aqua, are significantly different ($F(9,5)= 2.59$, $p < .05$).

Errors. Figure 6 shows the mean number of errors made with each set size. No errors were made with the set of two colors, and the number of errors was rather constant with set sizes of three to eight. There was, however, a sharp rise in the number of errors for set sizes of nine and ten. The number of errors was significantly different for the different set sizes, according to an analysis of variance ($F(8,5)= 2.84$, $p < .05$), and the Tukey test showed that the number of errors for the set size of 10 was greater than that for all the other set sizes except nine. The number of errors for the set size of nine was greater than those for set sizes of two and three.

Figure 7 shows the number of errors divided by the total number of stimulus presentations which of course varied with set size. The general picture is not particularly changed.

It is particularly important to keep in mind the differences in the number of presentations when trying to determine the error rates for the different colors. The colors were not all presented an equal number of times. The set of two consisted of dark blue and yellow; these two colors were therefore presented in all of the 10 sets, and the six subjects had a total of 600 chances to make a matching error. Light blue, on the other hand, was presented only in the set of 10, and the six subjects had only 60 chances to make an error with this color. The subjects made seven errors to the dark blue stimulus and only two errors with the light blue stimulus, but these figures correspnd to error rates of .013 for the dark blue and .03 for the light blue, a ratio of 2.5 to one favoring the dark blue. Figure 8 shows the error rates calculated in this way for the 10 colors.

Finally, there was little correlation between the RTs to the various colors and the error rates in the matches to each color ($r = .16$).

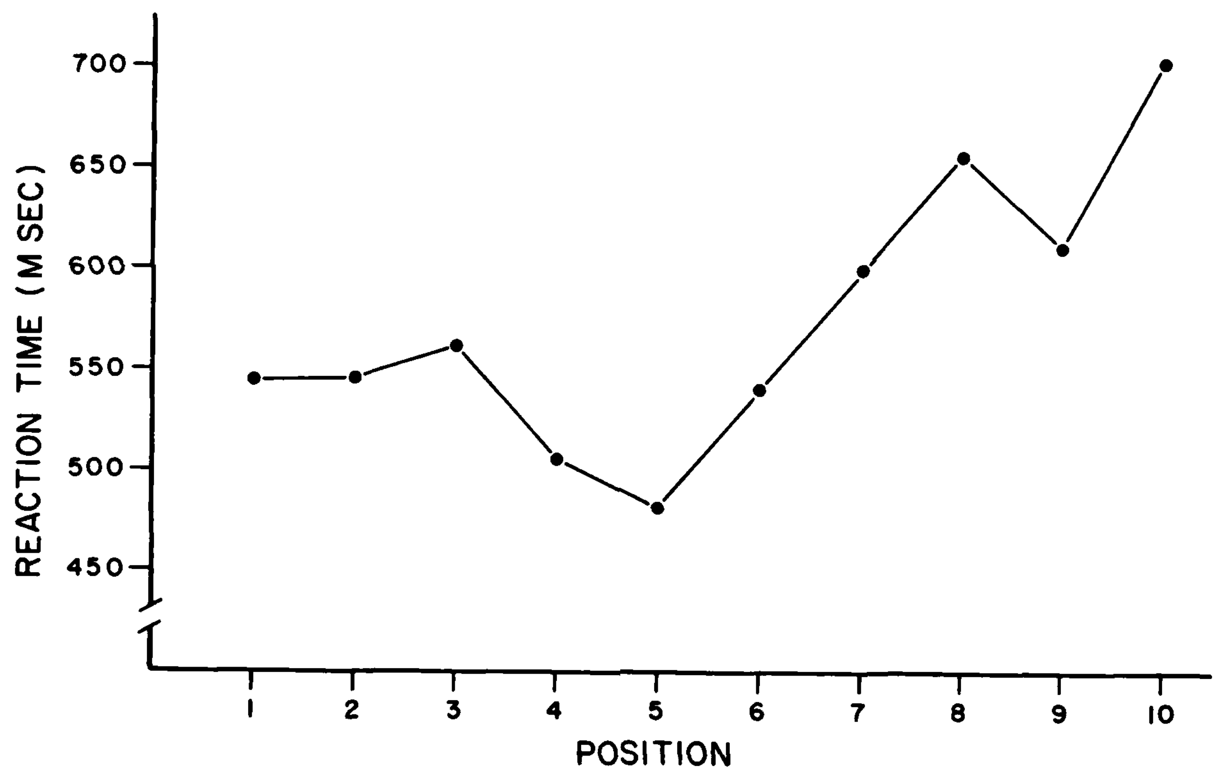

Fig. 4. Mean reaction time to white stimuli presented at each of the 10 locations in the telephone keypad arrangement.

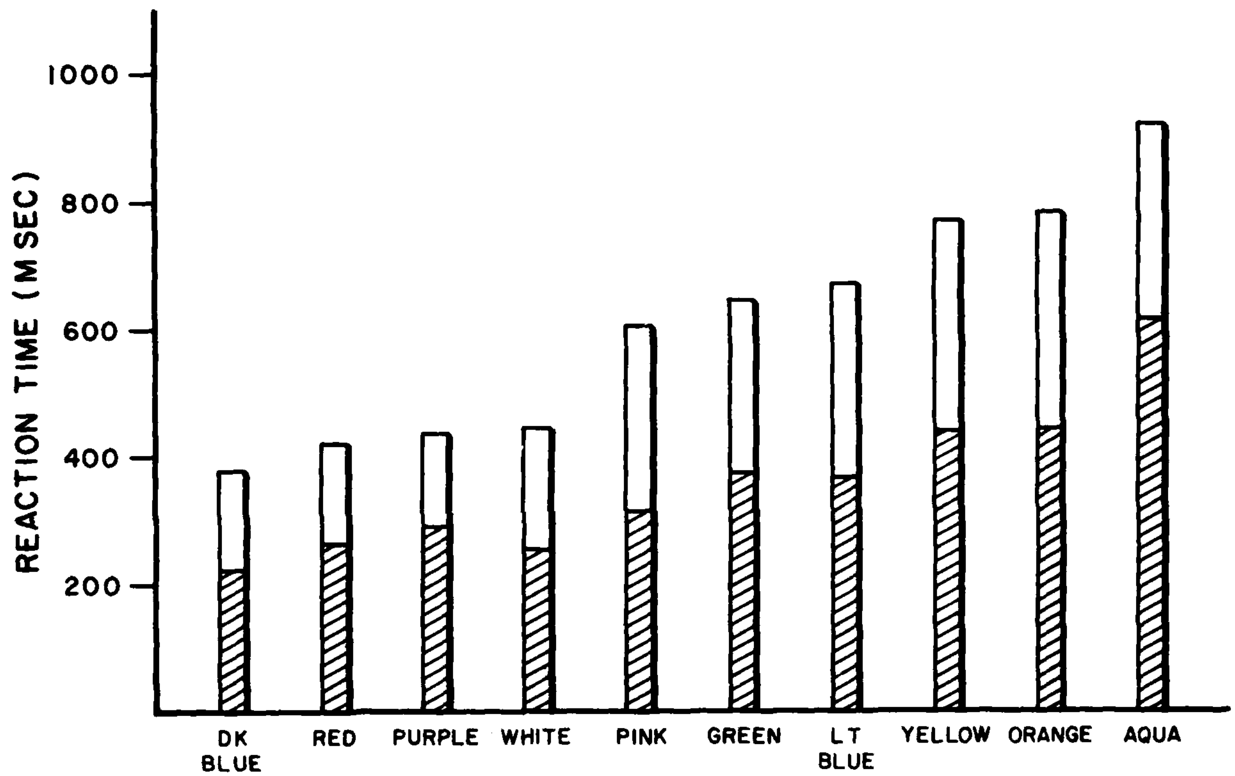

Fig. 5. Mean reaction times to the different colors corrected for differences in reaction-time to the location at which each color was presented. The open bars show the results in Experiment I, the hatched bars in Experiment II.

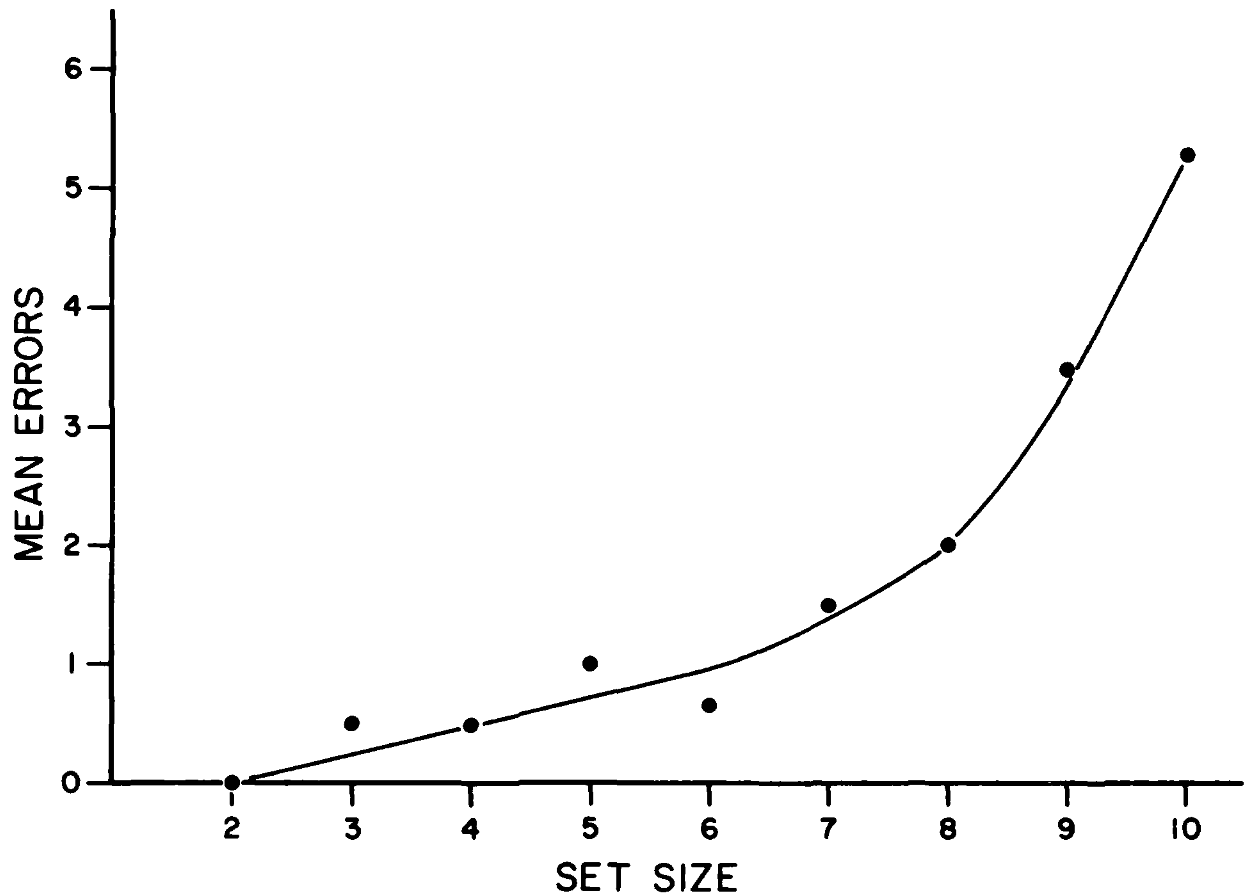

Fig. 6. Mean number of errors made with each set size in Expt. I.

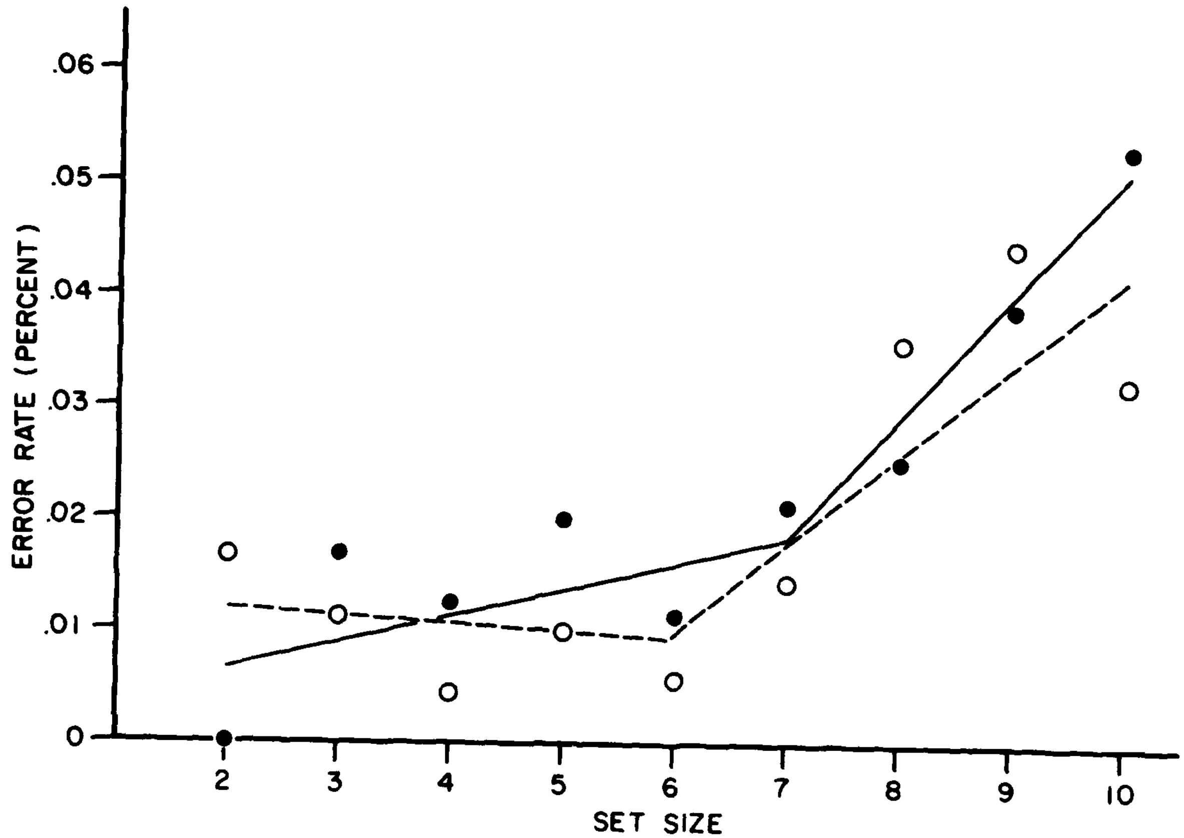

Fig. 7. Error rates in percent for each set size. The filled circles are for Expt. I, the open circles for Expt. II. The regression lines are the least squares solutions for the first six points and the last four points in each experiment.

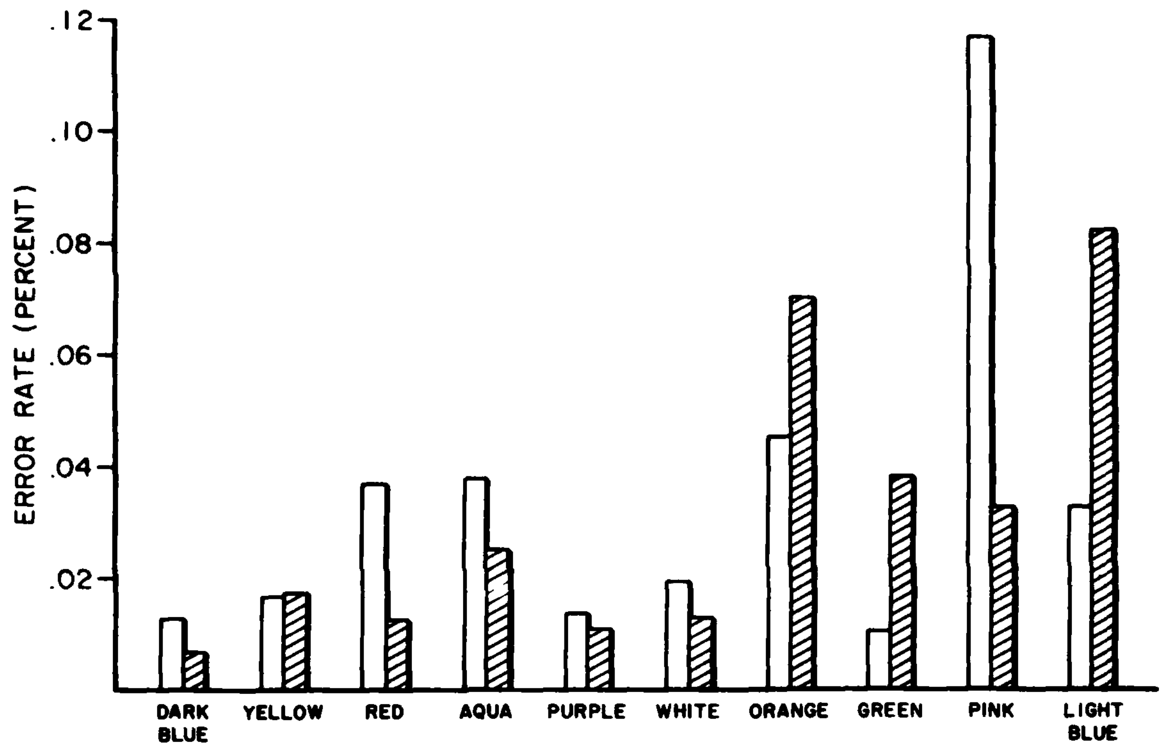

Fig. 8. Error rates, corrected for number of presentations, for the 10 colors in both Experiment I (open bars) and Experiment II (cross-hatched bars).

EXPERIMENT II

In the first experiment the colors were displayed in a different position with each set size. The subjects therefore had to search out the position of the matching color even when it was obvious to them which color it was. This of course was more difficult and time consuming as the set size increased. We wanted to determine how the results would be changed if the positions of the colors were more certain. In this experiment, therefore, the procedure was modified so that the subjects would not have to search for the locations of the colors they were seeking.

METHOD

Subjects. The subjects were those from the first experiment.

Apparatus. The same apparatus was used as in the first experiment.

Procedure. The set sizes were presented in order of increasing size. The circular outlines were again always visible, and in this experiment the colors were always presented in the same locations. For example, the colors presented in the set size of two were dark blue and yellow; the dark blue in this set and in all succeeding sets occupied the first circle, while yellow occupied the second circle. In the set of three, red was added to the third location and remained there for all the succeeding sets, and so on. Figure 9 shows the locations of the colors and also the location of the colors for the set size of 10 in Expt. I.

Again, the vertical line appeared (preceded by a tone one second before its appearance) in one of the colors in the set, positioned below the tenth circle, and the subject's task was to match it to the correct color in the set as quickly as possible. Again each color was presented randomly until the subject had responded correctly 20 times to the two-color set, 30 times to the three-color set, and so on.

RESULTS

Effect of Set Size on Reaction Time. Figure 10 shows the mean RTs to the various set sizes with the RTs to the achromatic stimuli again subtracted from them. Although the RTs are now shorter than in the previous experiment, the general picture is quite similar. The mean RT to the set size of two is 80 msec. As set size increases to three and four, mean RT increases by about 50 msec for each additional color. With further increases in set size up to 10, however, the increment in RT decreases to about 30 msec for each additional color. Once again, the same phenomenon is found for the uncorrected RTs, although they are, of course, longer.

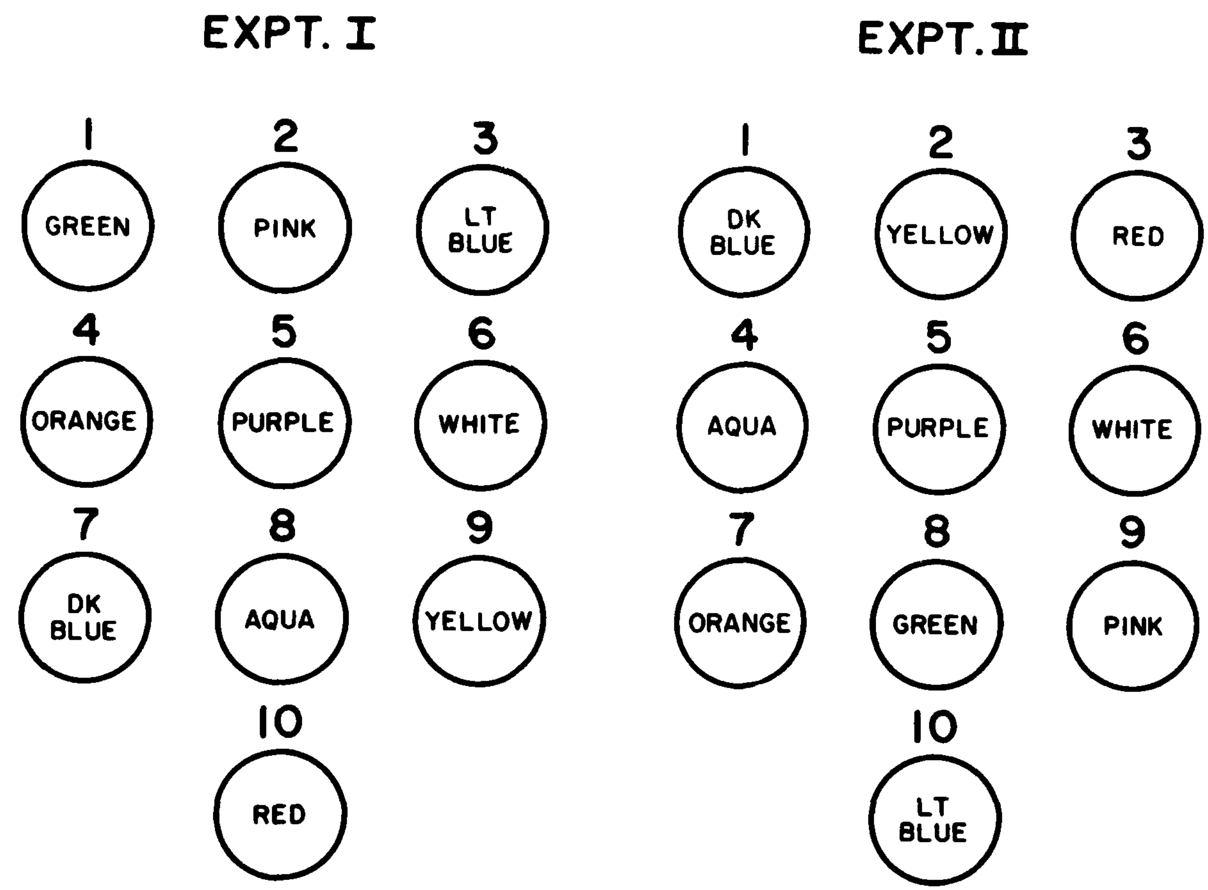

Fig. 9. Location of the colors for the set size of 10 in each experiment.

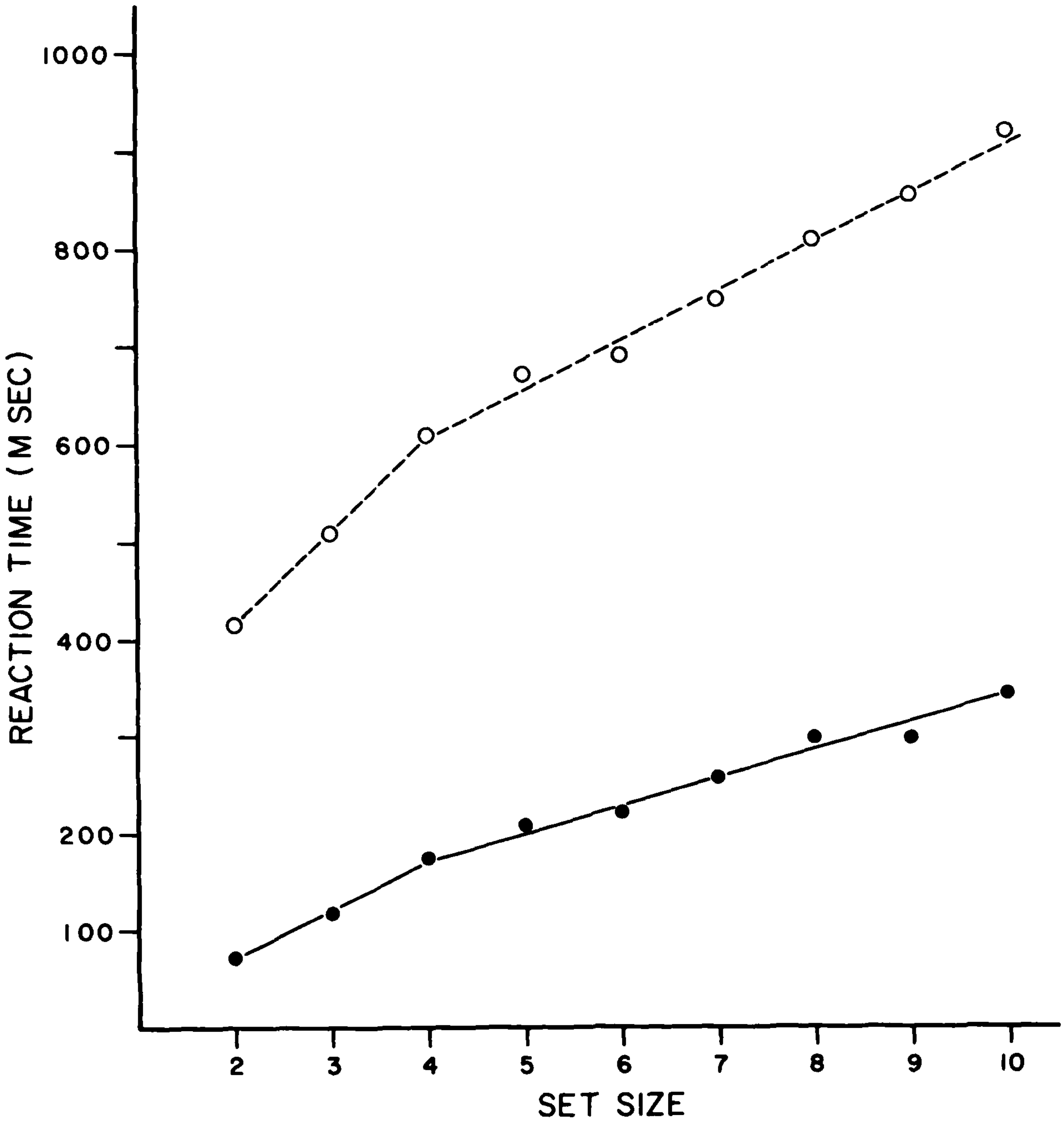

Fig. 10. Mean reaction times for each set-size, in Experiment II. Both the actual matching times (open circles) and the times corrected for the location of each color (filled circles) are shown.

Color Mismatches. Table III gives the errors in color matches. A large number of errors were made to the yellow, aqua, and orange stimuli. They were primarily confused with orange, green, and red, respectively. The former were the three worst colors in terms of RT also.

RTs to the Individual Colors. The RTs to the various colors were significantly different for each individual subject. Once again, part of this may be due to differences in the location of the colors. Figure 5 shows the RTs to the various colors corrected for their location. The correlation between the RTs in Expt. I and Expt. II is .96. It is clear that despite the differences in procedure and the difference in their location in the two experiments (see Fig. 9), the value of the colors remained constant. Dark blue, red, purple, and white were responded to most quickly; yellow, orange, and aqua gave the sujects the most difficulty.

It should be noted, however, that despite the remarkable similarity in the two sets of results in Fig. 5, the differences in RT to the various colors in this experiment were not significant. That is, when the subjects knew the location of the colors, the differences in RT were not significantly different

Errors. Fig. 11 shows the mean number of errors for each set size. The number of errors as a function of set size remains rather constant up to a set size of seven, after which it increases sharply (Fig. 4). The number of errors was significantly different for the different set sizes ($F(8,5)= 3.67$, $p < .01$). The Tukey test showed that the number of errors for the set size of nine was greater than those for set sizes of two to six. The correlation between the errors for the individual colors in the two experiments was not significant (r = .24).

The error rates for each color, again calculated on the basis of the number of presentations of each color, are shown in Fig. 7. Again, this figure shows that the error rate remained rather constant until the set size was eight or larger.

DISCUSSION

We expected to find that as the number of colors in the set increased, the increment in RT would also increase, perhaps exponentially. Nothing of the sort occurred, obviously. Whether the position of the colors was changed with set size or whether a given color always maintained the same position, the increment in RT with each additional color in the set maintained a given value for sets of four or five after which the size of the increment was reduced by about half and remained at that value up to a set size of 10. We do not know to what size the set can be increased and still exhibit this characteristic, but it seems likely that this will be the case as long as the the colors in the set remain quite distinguishable. Essentially the same results have

Table III. Mismatches to the stimulus colors in Expt. II.

	Stimulus Colors									
Subj.	D.Blue	Yellow	Red	Aqua	Purple	White	Orange	Green	Pink	L.Blue
RR	Aqua	Orange (4)	Orange	White	Green (2)		Aqua Red (2)	Purple Pink L.Blue Yellow		D.Blue Orange
AJ	Aqua	Red	Yellow	Purple	Aqua	Pink			White	
CS		D.Blue Orange	Yellow	Green (8) White		Purple Pink Yellow	Red (7)		Yellow (2)	
JD				Yellow	Green		Red (2)	Aqua	Whtie	
JS	Yellow		D.Blue				Aqua Red (2)	Purple		White Green
DK		D.Blue Orange	Yellow White				Aqua (2)	L.Blue		Green
Total Errors	3	9	6	12	4	4	17	7	4	5

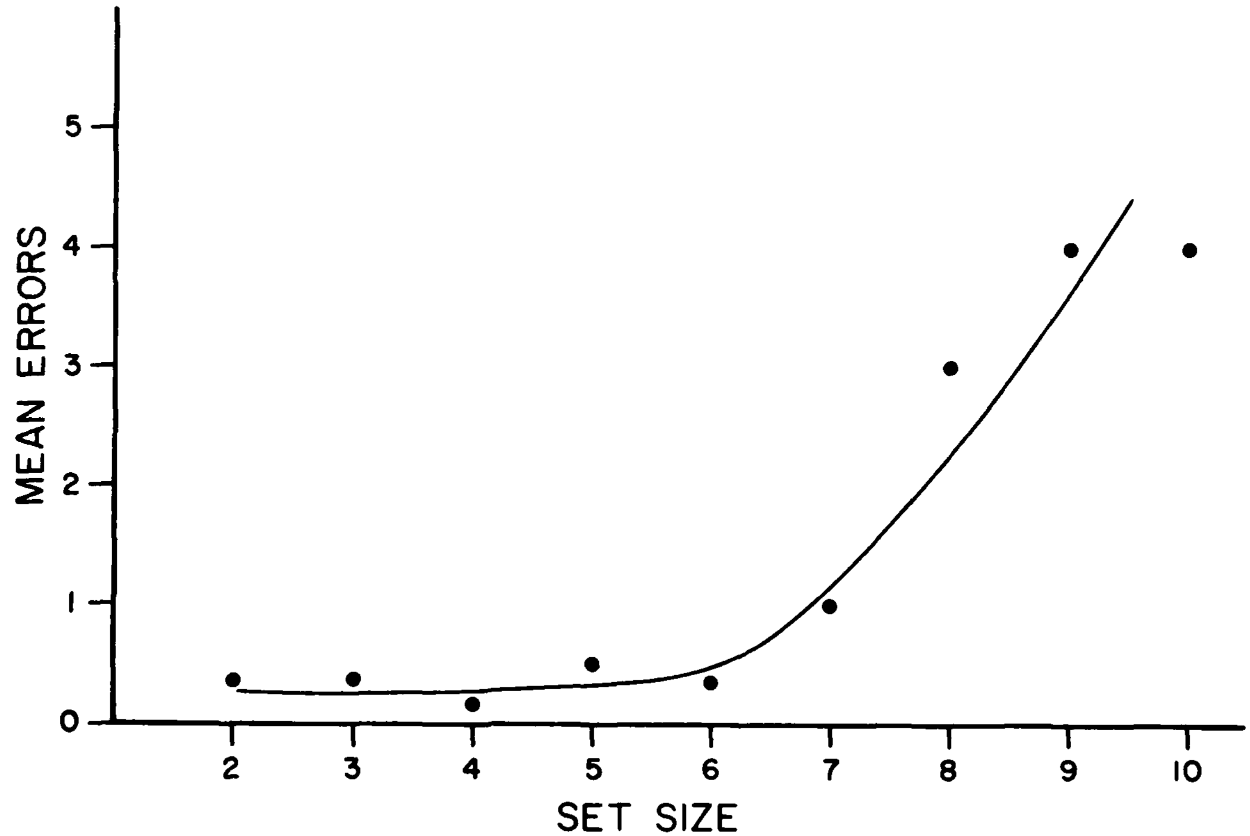

Fig. 11. Mean number errors with each set size in Expt. II.

been found by Jacobsen and Neri (22) in a study of color memory. It is clear, then, that the use of 10 colors for a color coding system requiring either color matching or color memory should pose no problems for CRT operators.

Although the mean RT does not increase exorbitantly with an increase in the number of colors in the set up to 10, the mean number of matching errors increased sharply with set sizes of more than seven. RT may remain relatively short because the subjects either are confident of their matches or are willing to risk making errors, but the increase in errors indicates that there is an added risk of confusion as the set size increases. It is possible, of course, that with the proper choice of colors, a larger set size can be chosen without an increase in errors.

The second notable finding is the stability of these colors when ordered according to RT. Again, whether the colors maintained their position throughout the experiment or not, the same colors resulted in good or bad RTs. Dark blue, red, purple, and white were most quickly matched, while yellow, orange, and aqua were most slowly matched. These results are not a function of contrast, since yellow was a much brighter color than red, for example; the explanation must lie in the discriminability of the colors from the other colors in the set. Orange was often confused with red and yellow was often confused with orange--but, interestingly, not the other way around. How effective a given color is, therefore, depends on the other colors in the set.

Finally, the method used in this study appears to be an efficient and objective way to evaluate and compare the discriminability and overall usefulness of different color sets. The overall RT, compared to the RT of other sets, indicates how good the set is, while the RT for each color in the set indicates the extent to which each color may be confused with other colors in the set. The matching procedure can be carried out quite quickly, in sharp contrast to other types of evaluations such as paired comparisons of colors in a set.

REFERENCES

1. Christ, R. E. Review and analysis of color coding research for visual displays. Human Factors 17, 542-570, 1975.

2. Cook, T. C. Color coding--A review of the literature. U. S. Army Human Engineering Laboratory, Tech. Note 9-74, Nov 1974.

3. Teichner, W. H., Christ, R. E., and Corso, G. M. Color research for visual displays. ONR Rep. CR213102-4F. New Mexico State University, 1977.

4. Krebs, M. J., Wolf, J. D., and Sandvig, J. H. Color display design guide. ONR Rep. CR213-136-2F, Honeywell Systems Research Center, Minneapolis, MN, Oct 1978.

5. Neil, D. E. Application of color coding in tactical display S-3A. Naval Postgraduate School, Monterey, CA, Rep. No. NP355-80-113, Apr 1980.

6. Neri, D. and Zannelli, D. Guidelines for the use of color in SUBACS A displays. NSMRL & NUSC Joint Rep No. 1032, 16 Oct 1984.

7. Laycock, J. Recommended colours for use on airborne displays. Royal Aircraft Establishment, Tech. Rep 82110, Nov 1982.

8. Jones, M. R. Color coding. Human Factors 4, 355-365, 1962.

9. Halsey, R. M. and Chapanis, A. On the number of absolutely identifiable spectral hues. J. Opt. Soc. Am. 41, 1057-1058, 1951.

10. Baker, C. A. and Grether, W. F. Visual presentation of information. Wright Air Development Center, WADC-TR-54160, 1954.

11. Conover, D. W. and Kraft, C. L. The use of color in coding displays. Wright Air Development Center, WADC-TR-55-471, 1958.

12. Conover, D. W. The amount of information in the absolute judgment of Munsell hues. Wright Air Development Center, WADC-TR-58-262, 1959.

13. Brooks, R. Search time and color coding. Psychonomic Science 2, 281-282, 1965.

14. Semple, C. A. Jr., Heapy, R. J., Conway, E. J. Jr., and Burnett, K. T. Analysis of human factors data for electronic flight display systems. Tech. Rep. No. AFFDL-TR-70-174, 1971.

15. Connolly, D. W., Spanier, G., and Champion, F. Color display evaluation for air traffic control. Federal Aviation Administration Rep. No. FAA-RD-75-39, 1975.

16. Haeusing, M. Color coding of information on electronic displays. Proceedings of the Sixth Congress of the International Ergonomics Association. pp 210-217, 1976.

17. Meister, D. and Sullivan, D. J. Guide to human engineering design for visual displays. Bunker-Ramo Corp., Canoga Park, CA, 1969.

18. Butler, W. B. and McKemie, W. M. Engineering guidelines for the use of color in a sonar display. Tracor Document No. T73-AU-9550-U, Tracor Sciences and Systems, Austin, TX. 1974.

19. Kelly, K. L., Gibson, K. S. and D. Nickerson, Tristimulus specification of the Munsell Book of Color from spectrophotometric measurements. J. Opt. Soc. Am. 33, 355-375, 1943.

20. Granville, W. C., Nickerson, D., and Foss, C. E. Trichromatic specifications of the intermediate and special colors of the Munsell system. J. Opt. Soc. Am. 33, 376-385, 1943.

21. Nickerson, D., Tomaszewski, J. J., and Boyd, T. F. Colorimetric specifications of Munsell repaints. J. Opt. Soc. Am. 43, 163-171, 1953.

22. Jacobsen, A. R. and Neri, D. F. The effect of set size on color recognition. NSMRL Rep. (in preparation)

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The time required to match a colored stimulus to one of a set of colors was measured as a function of color sets ranging in size from 2 to 10. Reaction time (RT) increased linearly with increases in set-size to five or six, after which the increase, although still linear, was less steep. Mean errors increased sharply with set sizes of 9 and 10. The relative RTs to the different colors remained constant despite changes in the experimental method.